US009829900B2

(12) United States Patent
Suzuki

(10) Patent No.: US 9,829,900 B2
(45) Date of Patent: Nov. 28, 2017

(54) **VOLTAGE REGULATOR**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/367,802**

(22) Filed: **Dec. 2, 2016**

(65) **Prior Publication Data**

US 2017/0160764 A1 Jun. 8, 2017

(30) **Foreign Application Priority Data**

Dec. 7, 2015 (JP) 2015-238818

(51) **Int. Cl.**

G05F 1/56	(2006.01)
G05F 1/569	(2006.01)
G05F 1/46	(2006.01)
G05F 3/16	(2006.01)
G05F 1/567	(2006.01)
G05F 1/573	(2006.01)
G05F 1/565	(2006.01)

(52) **U.S. Cl.**

CPC ***G05F 1/569*** (2013.01); ***G05F 1/468*** (2013.01); ***G05F 1/562*** (2013.01); *G05F 1/565* (2013.01); *G05F 1/567* (2013.01); *G05F 1/573* (2013.01); *G05F 3/16* (2013.01)

(58) **Field of Classification Search**

CPC . G05F 1/468; G05F 1/56; G05F 1/562; G05F 1/565; G05F 1/567; G05F 1/569; G05F 1/573; G05F 1/575

See application file for complete search history.

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(57) **ABSTRACT**

The voltage regulator includes an overheat protection circuit. The overheat protection circuit includes: a temperature sensing circuit; a voltage difference sensing circuit configured to output a current depending on a voltage difference between a power source voltage to be supplied to a power supply terminal and the output voltage; an output current monitoring circuit; a second reference voltage circuit configured to generate a second reference voltage; a comparator circuit configured to compare an output voltage of the temperature sensing circuit and the second reference voltage to each other; and an overheat protection transistor is configured to turn off the output transistor when the result of the comparison indicates an overheated state. The second reference voltage of the second reference voltage circuit is controlled based on an output current of the voltage difference sensing circuit and on an output current of the output current monitoring circuit.

6 Claims, 3 Drawing Sheets

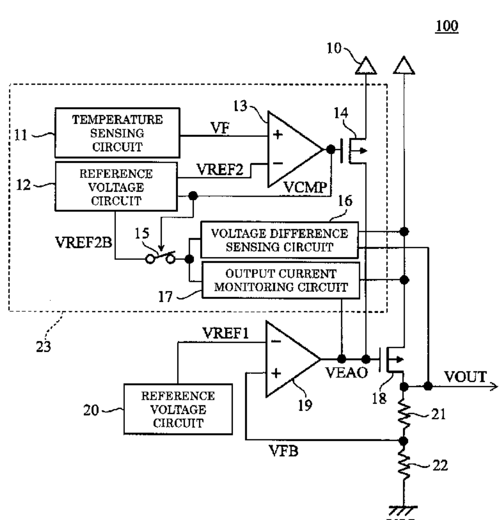

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FIG. 1

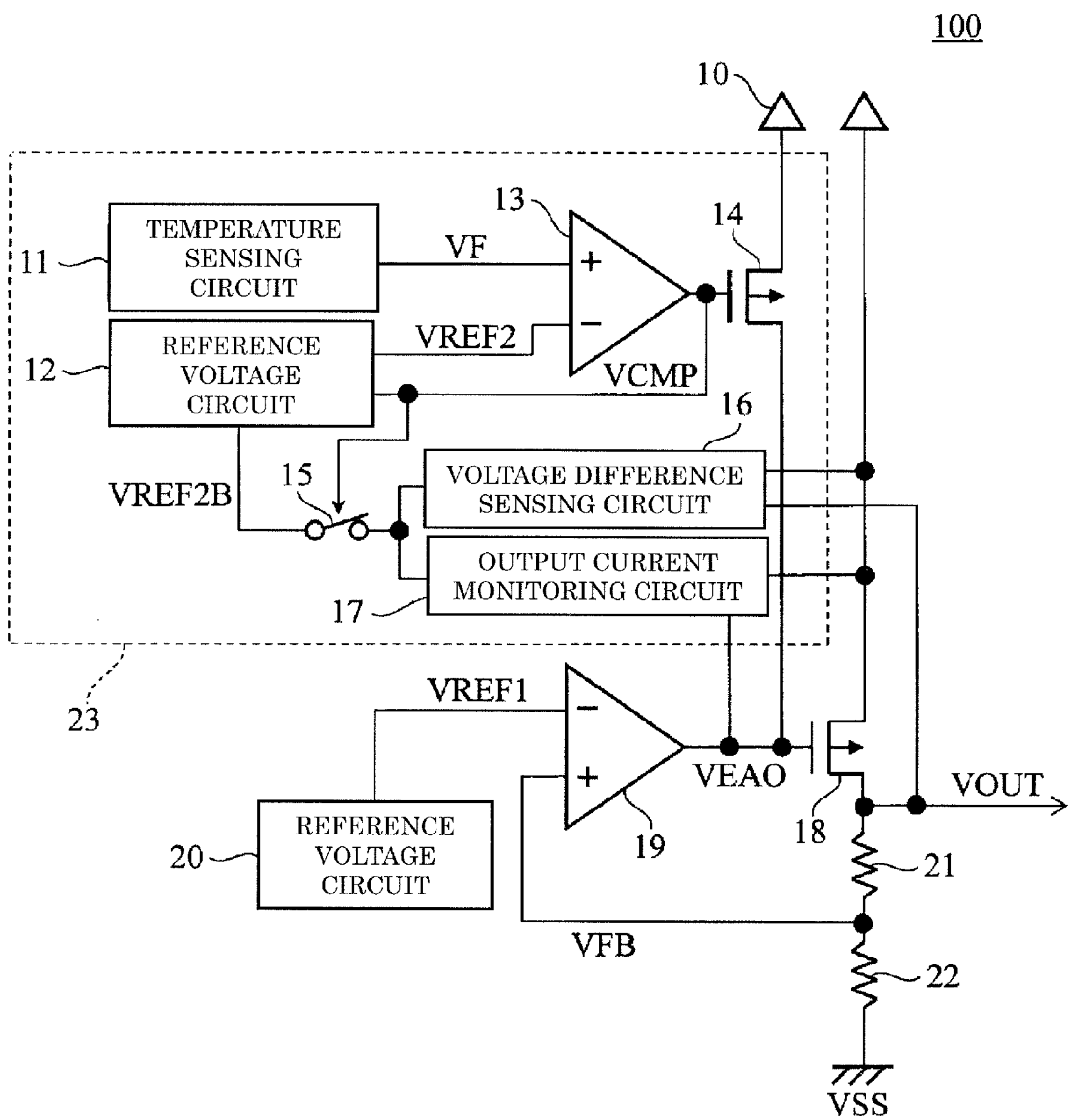

100
10
13
14
11
TEMPERATURE SENSING CIRCUIT
VF
12
REFERENCE VOLTAGE CIRCUIT
VREF2
VCMP
16
VREF2B
15
VOLTAGE DIFFERENCE SENSING CIRCUIT
OUTPUT CURRENT MONITORING CIRCUIT
17
23
VREF1
VEAO
VOUT
18
19
20
REFERENCE VOLTAGE CIRCUIT
21
VFB
22
VSS

FIG. 2

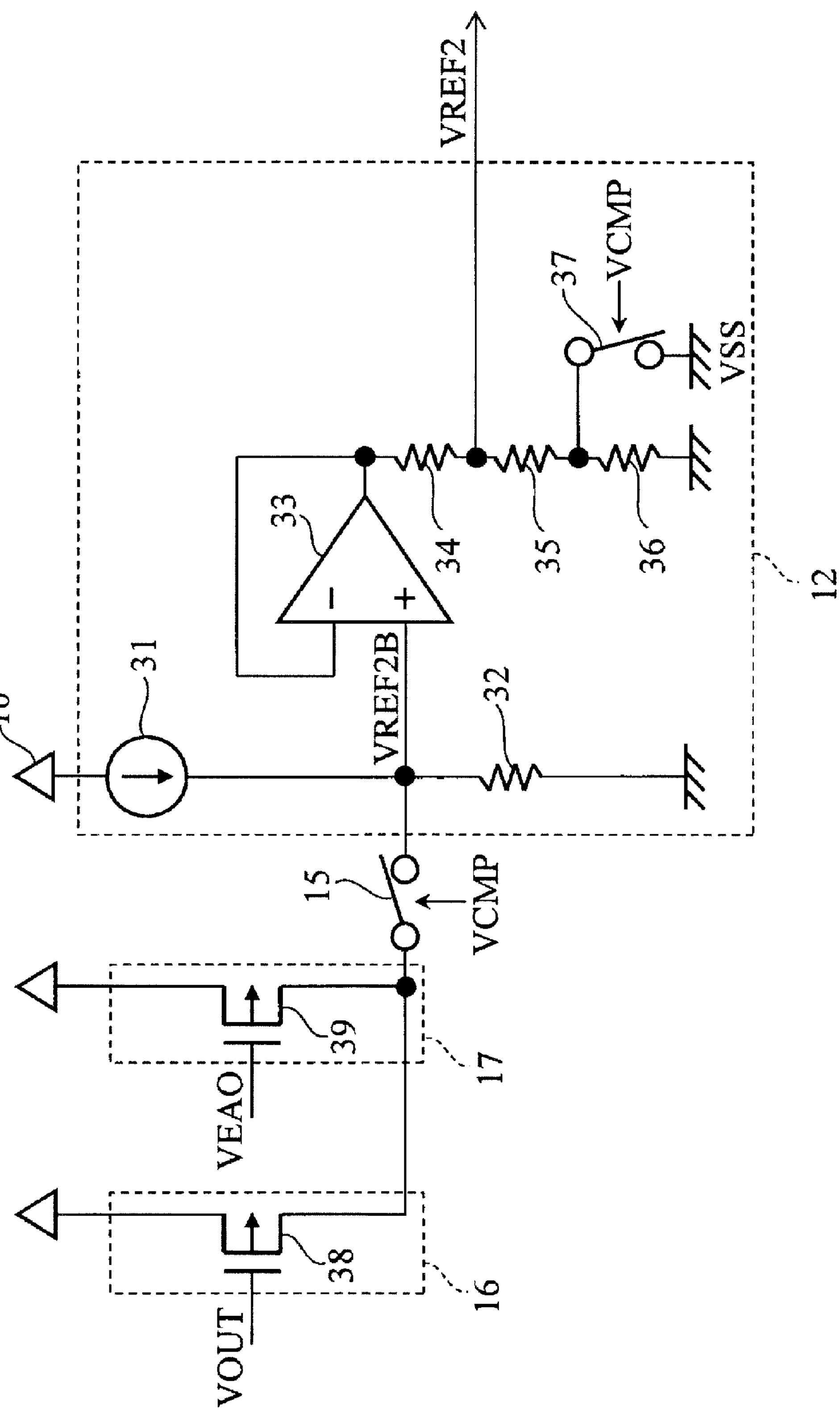
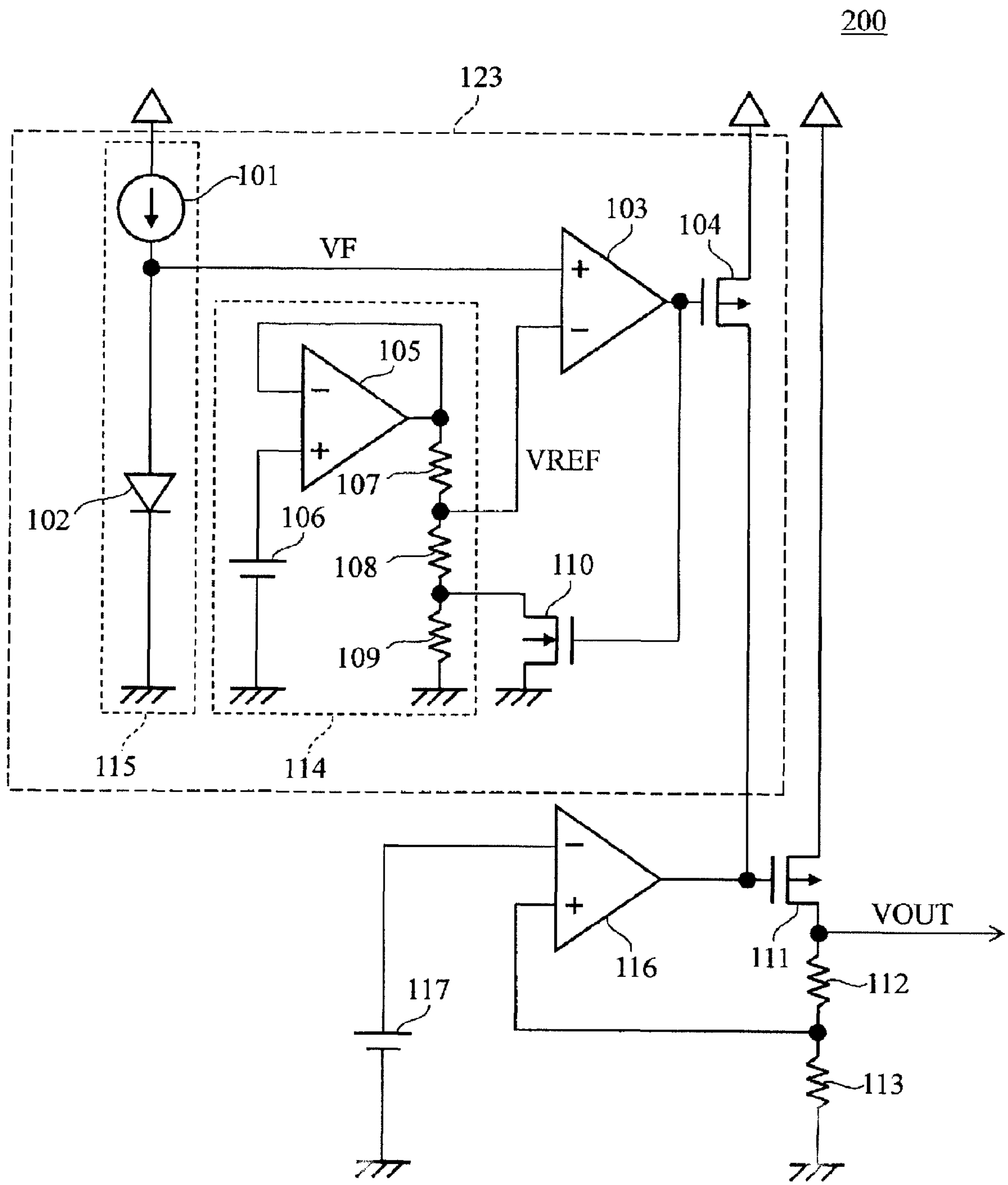

VREF2
VCMP
37
VSS
33
34
35
36
12
31
10
VREF2B
32
15
VCMP
39
17
VEAO
38
16
VOUT

FIG. 3
PRIOR ART



VOLTAGE REGULATOR

RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119 to Japanese Patent Application No. 2015-238818 filed on Dec. 7, 2015, the entire content of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a voltage regulator including an overheat protection circuit.

2. Description of the Related Art

In general, a voltage regulator is configured to supply a current depending on a load of an electronic device connected to an output port, and energy consumption due to heat generation leads to electric power loss. Further, when a load current increases, a temperature of the voltage regulator rises excessively and the voltage regulator itself may be damaged. Accordingly, there is provided an overheat protection circuits configured to prevent the voltage regulator from reaching a predetermined temperature or higher.

Here, a related-art voltage regulator including an overheat protection circuit is described (e.g., see Japanese Patent Application Laid-open No. 2005-100295).

FIG. **3** is a circuit diagram of a related-art voltage regulator **200**.

The voltage regulator **200** includes an overheat protection circuit **123** including a temperature sensing circuit **115**, a reference voltage circuit **114**, a comparator circuit **103**, and transistors **104** and **110**, and has the following configuration.

The temperature sensing circuit **115** is formed of a constant current circuit **101** and a diode **102**, and is configured to output a voltage VF from a node between the constant current circuit **101** and the diode **102**.

The reference voltage circuit **114** is formed of a reference voltage **106**, a voltage follower circuit **105**, and bleeder resistors **107**, **108**, and **109**, and is configured to output a voltage VREF from a node between the resistors **107** and **108**.

The comparator circuit **103** is configured to compare the voltage VF, which is output of the temperature sensing circuit **115**, and the voltage VREF, which is output of the reference voltage circuit **114**, to each other, and to output the result of the comparison. Output of the comparator circuit **103** is input to a gate of the transistor **104** and a gate of the transistor **110**.

The transistor **104** has a source connected to a power supply terminal, and a drain connected to a gate of an output transistor (output driver) **111** of the voltage regulator **200**. The transistor **110** has a source connected to a ground terminal, and a drain connected to a node between the resistors **108** and **109**.

A voltage divider circuit formed of the resistors **112** and **113** is connected between a drain of the output transistor **111** and the ground terminal.

An error amplifier circuit **116** is configured to receive a divided voltage from the voltage divider circuit and a voltage of a reference voltage **117**, and has an output terminal connected to the gate of the output transistor **111**.

Temperature characteristics of the temperature sensing circuit **115** are based on temperature characteristics of a forward voltage of the diode **102**, and the output voltage VF has a characteristic of being substantially −2 mV/° C. The output voltage VREF of the reference voltage circuit **114** may be set to any voltage value through adjustment of the bleeder resistors **107**, **108**, and **109** by trimming.

In a normal state in which an overheated state is not detected, VF>VREF holds. Thus, the output of the comparator circuit **103** becomes a HIGH state, and the transistor **104** is turned off. As a result, a gate voltage of the output transistor **111** reaches a voltage of the output terminal of the error amplifier circuit **116**. Consequently, the output transistor is turned on, and an output voltage VOUT having a predetermined potential is output.

When the overheated state is detected, on the other hand, VREF>VF holds. Thus, the output of the comparator **103** becomes LOW, and the transistor **104** is turned on. As a result, the gate voltage of the output transistor **111** reaches a power source voltage, and the output transistor **111** is thus turned off Consequently, the output voltage VOUT has a ground potential.

As described above, when the overheat protection circuit **123** does not detect the overheated state, the related-art voltage regulator **200** normally operates and outputs, from the output transistor **111**, the predetermined voltage VOUT having a power source potential or lower. When the overheat protection circuit **123** detects the overheated state, the related-art voltage regulator **200** turns off the output transistor **111** so that the output voltage VOUT has the ground potential. In this way, the voltage regulator itself may be protected from an excessive temperature rise thereof.

The transistor **110** is provided in order that the voltage regulator is changed from the overheated state to the normal state, and reversely from the normal state to the overheated state at different temperatures, that is, the voltage regulator has hysteresis.

In high-voltage and high-current voltage regulators, a large amount of electric power is lost due to a translational increase in load current under a high voltage state. The electric power is lost mainly due to energy consumption by an output driver generating heat. However, when the output driver and a diode of a temperature sensing circuit are arranged on a chip at positons away from each other, there is a temperature difference between a temperature near the center of the output driver at which heat is generated by the largest amount and a temperature at the diode of the temperature sensing circuit, due to thermal gradient.

In the related-art voltage regulator **200** of FIG. **3**, there is a fear in that at a time when the overheat protection circuit **123** detects a predetermined overheated state, a temperature near the center of the output driver (output transistor **111**) at which heat is generated by the largest amount may reach a temperature of the predetermined overheated state or higher, and exceed a heat resistant temperature of the output driver **111** to damage the output driver **111**.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above-mentioned problem, and provides a voltage regulator capable of preventing an output driver from being damaged due to heat.

According to one embodiment of the present invention, there is provided a voltage regulator, including: an output transistor configured to output an output voltage; a first reference voltage circuit configured to generate a first reference voltage; a voltage divider circuit configured to divide the output voltage to generate a divided voltage, and to output the divided voltage; an error amplifier circuit configured to receive the first reference voltage and the divided voltage, and to control the output transistor such that the output voltage is constant; and an overheat protection circuit configured to detect an overheated state, and to turn off the output transistor, the overheat protection circuit including: a temperature sensing circuit configured to output a voltage depending on temperature; a voltage difference sensing circuit configured to output a current depending on a voltage difference between a power source voltage to be supplied to a power supply terminal and the output voltage; an output current monitoring circuit configured to output a current depending on a current flowing through the output transistor; a second reference voltage circuit configured to generate a second reference voltage; a comparator circuit configured to compare an output voltage of the temperature sensing circuit and the second reference voltage to each other; and an overheat protection transistor that includes a gate for receiving a result of the comparison by the comparator circuit, and is configured to turn off the output transistor when the result of the comparison indicates the overheated state, the second reference voltage of the second reference voltage circuit being controlled based on an output current of the voltage difference sensing circuit and on an output current of the output current monitoring circuit.

According to the present invention, the second reference voltage is controlled based on an output current of the voltage difference sensing circuit, which is configured to output a current depending on a voltage difference between the power source voltage to be supplied to the power supply terminal and the output voltage, and on an output current of the output current monitoring circuit, which is configured to output a current depending on a current flowing through the output transistor. With such a configuration, the output transistor can be turned off based on an increase in electric power consumption by the output transistor. It is therefore possible to prevent the output transistor from being damaged due to heat.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit diagram of a voltage regulator having a built-in overheat protection circuit according to one embodiment of the present invention.

FIG. **2** is a circuit diagram of a reference voltage circuit, an electric power detecting circuit, a voltage difference sensing circuit, and an output current monitoring circuit in the overheat protection circuit illustrated in FIG. **1**.

FIG. **3** is a circuit diagram of a related-art voltage regulator having a built-in overheat protection circuit.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, an embodiment of the present invention is described with reference to the drawings.

FIG. **1** is a circuit diagram of a voltage regulator **100** of the present invention.

The voltage regulator **100** includes an output transistor (output driver) **18**, an error amplifier circuit **19**, a reference voltage circuit **20**, a voltage divider circuit formed of resistors **21** and **22**, and an overheat protection circuit **23**, and has the following configuration.

The error amplifier circuit **19** is configured to compare a divided voltage VFB generated by dividing an output voltage VOUT by the voltage divider circuit, and a reference voltage VREF**1** generated by the reference voltage circuit **20** to each other. The error amplifier circuit **19** is configured to output a voltage VEAO as the result of the comparison to supply a gate of the output transistor **18** with the voltage VEAO.

With such a configuration, the voltage regulator **100** outputs a constant output voltage VOUT from an output terminal thereof in a normal state.

The overheat protection circuit **23** is formed of a temperature sensing circuit **11**, a reference voltage circuit **12**, a comparator circuit **13**, a PMOS transistor (overheat protection transistor) **14**, a switch **15**, a voltage difference sensing circuit **16**, and an output current monitoring circuit **17**.

The temperature sensing circuit **11** has a configuration similar to that of the temperature sensing circuit **115** illustrated in FIG. **3**. Temperature characteristics of the temperature sensing circuit **11** are based on temperature characteristics of a forward voltage of a diode, and an output voltage VF has a characteristic of being substantially −2 mV/° C.

The comparator circuit **13** is configured to compare the output voltage VF of the temperature sensing circuit **11** and an output voltage VREF**2** of the reference voltage circuit **12** to each other, and to output a voltage VCMP as the result of the comparison. The output voltage VCMP of the comparator circuit **13** is supplied to a gate of the PMOS transistor **14** having a source connected to the power supply terminal **10** and a drain connected to a gate of the output transistor **18**.

The voltage difference sensing circuit **16** is connected to the power supply terminal **10**, the output terminal of the voltage regulator **100**, and one end of the switch **15**.

The output current monitoring circuit **17** is connected to the power supply terminal **10**, an output terminal of the error amplifier circuit **19**, and the one end of the switch **15**.

The other end of the switch **15** is connected to the reference voltage circuit **12**, and the switch **15** is controlled to be turned on and off with the output voltage VCMP of the comparator circuit **13**. The switch **15** is turned on when the voltage VCMP is HIGH, and is turned off when the voltage VCMP is LOW.

Next, the details of the reference voltage circuit **12**, the switch **15**, the voltage difference sensing circuit **16**, and the output current monitoring circuit **17** that are illustrated in FIG. **1** are described with reference to FIG. **2**.

The reference voltage circuit **12** is formed of a constant current circuit **31**, a resistor **32**, a voltage follower circuit **33**, bleeder resistors **34**, **35**, and **36**, and a switch **37**.

The bleeder resistors **34**, **35**, and **36** are connected between an output of the voltage follower circuit **33** and a ground terminal VSS.

The switch **37** has one end connected to a node between the resistors **35** and **36**, and the other end connected to the ground terminal VSS, and is controlled to be turned on and off with the output voltage VCMP of the comparator circuit **13**. The switch **37** is turned on when the voltage VCMP is HIGH, and is turned off when the voltage VCMP is LOW.

A node between the constant current circuit **31** and the resistor **32** is connected to one input terminal of the voltage follower circuit **33**.

The voltage difference sensing circuit **16** is formed of a transistor **38** having a source connected to the power supply terminal **10**, a gate connected to VOUT, and a drain connected to the one end of the switch **15**. Further, the output current monitoring circuit **17** is formed of a transistor **39** having a source connected to the power supply terminal **10**, a gate connected to the gate of the output transistor **18** illustrated in FIG. **1**, and a drain connected to the one end of the switch **15**.

Next, the operation of the overheat protection circuit **23** is described with reference to FIG. **1** and FIG. **2**.

In the normal state, the reference voltage circuit **12** outputs the voltage VREF**2** having a predetermined voltage value corresponding to a predetermined temperature for detecting an overheated state.

When a temperature of the voltage regulator **100** increases due to self-heating or increasing peripheral temperature, the output voltage VF of the temperature sensing circuit **11** decreases with the characteristic of being about −2 mV/° C. Then, the comparator circuit **13** outputs LOW when the output voltage VF of the temperature sensing circuit **11** falls below the output voltage VREF**2** of the reference voltage circuit **12**.

As a result, the PMOS transistor **14** is turned on and a gate voltage of the output transistor **18** thus increases. Hence, the output transistor **18** is turned off, and the output voltage VOUT of the voltage regulator becomes LOW.

Next, as a main feature of the present invention, the operation of the overheat protection circuit **23** for preventing the output driver from being damaged due to heat is described.

Under the above-mentioned normal state, when a voltage difference between a power source voltage of the power supply terminal **10** and the output voltage VOUT increases, current flows from the power supply terminal **10** to the ground terminal VSS via the transistor **38** of the voltage difference sensing circuit **16**, the switch **15**, and the resistor **32**. Further, when an output current flowing through the output transistor **18** increases, current flows from the power supply terminal **10** to the ground terminal VSS via the transistor **39** of the output current monitoring circuit **17**, the switch **15**, and the resistor **32**.

As a result, a current flowing through the resistor **32** increases, and the voltage VREF**2**B at the node between the constant current circuit **31** and the resistor **32** increases. Consequently, the output voltage VREF**2** of the reference voltage circuit **12** exceeds the above-mentioned predetermined voltage value. That is, the second reference voltage VRERF**2** is controlled based on an output current of the voltage difference sensing circuit **16** and on an output current of the output current monitoring circuit **17**.

The output voltage of the temperature sensing circuit **11** has the constant characteristic of being about −2 mV/° C. Thus, the temperature for detecting the overheated state is set to a low value when the output voltage VREF**2** of the reference voltage circuit **12** increases.

Hence, when the reference voltage VREF**2** that has been increased by the voltage difference sensing circuit **16**, the output current monitoring circuit **17**, the switch **15**, and the reference voltage circuit **12** exceeds the output voltage VF of the temperature sensing circuit **11**, the output voltage VCMP of the comparator circuit **13** becomes LOW, and the PMOS transistor **14** is thus turned on.

As a result, the voltage VEAO to be supplied to the gate of the output transistor **18** reaches the power source voltage of the power supply terminal **10**. Then, the output transistor **18** is turned off, and the output voltage VOUT of the voltage regulator becomes LOW. In short, output of the voltage regulator is stopped.

At this time, the switches **15** and **37** are turned off based on the output voltage VCMP of the comparator circuit **13** being LOW.

Here, the switch **15** is turned off because of the following reason. Specifically, if the switch **15** is still on after the overheated state is detected and the output is stopped, there is a fear in that a current of the output current monitoring circuit may all flow out because the output is stopped, with the result that the voltage regulator may return to the normal state soon.

Further, the switch **37** is turned off in order to decrease a temperature for canceling the overheated state. Specifically, the reference voltage VREF**2** that has increased as described above is set to a voltage that is higher than the predetermined voltage value by a resistance value of the resistor **36**, by turning off the switch **37**. When the output voltage VREF**2** of the reference voltage circuit **12** is set to a high value, the reference temperature for canceling the overheated state after the overheated state is detected once may be set to a low value.

The output voltage of the temperature sensing circuit **11** increases when the output of the voltage regulator is stopped due to detection of the overheated state, and a temperature of the voltage regulator decreases. When the temperature falls below the predetermined temperature for canceling the overheated state, the output voltage of the temperature sensing circuit **11** exceeds the output voltage VREF**2** of the reference voltage circuit **12**, and the comparator circuit **13** outputs HIGH. Then, the PMOS transistor **14** is turned off, and the gate voltage of the output transistor **18** thus decreases. Consequently, the output transistor **18** is turned on, and the output voltage VOUT of the voltage regulator reaches the predetermined voltage again.

As described above, according to this embodiment, even when a temperature being sensed by the temperature sensing circuit **11** is lower than the predetermined temperature, the output voltage VREF**2** of the reference voltage circuit **12** is controlled based on a current that is output by the voltage difference sensing circuit **16** and depends on a voltage difference between the power source voltage and the output voltage VOUT, and on a current that is output by the output current monitoring circuit **17** and depends on a current flowing through the output transistor. In short, the output voltage VREF**2** is controlled based on electric power consumption by the output transistor **18**. In this way, the reference temperature for detecting the overheated state may be set to a low value. It is therefore possible to prevent the output transistor from being damaged due to heat.

As described above, according to the present invention, a detection temperature may be set to a low value when electric power loss is large. Further, a functional test of overheat protection circuits in mass production may be performed under low temperature by setting electric power loss to a large value such that a detection temperature decreases. When the test may be performed under low temperature, there are provided effects that waiting time for reaching a set temperature is reduced, and necessity of high-temperature members is eliminated to reduce costs.

What is claimed is:

1. A voltage regulator, comprising:

an output transistor configured to output an output voltage;

a first reference voltage circuit configured to generate a first reference voltage;

a voltage divider circuit configured to divide the output voltage to generate a divided voltage, and to output the divided voltage;

an error amplifier circuit configured to receive the first reference voltage and the divided voltage, and to control the output transistor such that the output voltage is constant; and

an overheat protection circuit configured to detect an overheated state, and to turn off the output transistor,

the overheat protection circuit comprising:

a temperature sensing circuit configured to output a voltage depending on temperature;

a voltage difference sensing circuit configured to output a current depending on a voltage difference between a power source voltage to be supplied to a power supply terminal and the output voltage;

an output current monitoring circuit configured to output a current depending on a current flowing through the output transistor;

a second reference voltage circuit configured to generate a second reference voltage;

a comparator circuit configured to compare an output voltage of the temperature sensing circuit and the second reference voltage to each other; and

an overheat protection transistor that includes a gate for receiving a result of the comparison by the comparator circuit, and is configured to turn off the output transistor when the result of the comparison indicates the overheated state,

the second reference voltage of the second reference voltage circuit being controlled based on an output current of the voltage difference sensing circuit and on an output current of the output current monitoring circuit.

2. A voltage regulator according to claim **1**, further comprising a first switch that is provided between an output of the voltage difference sensing circuit and an output of the output current monitoring circuit, and the second reference voltage circuit, the first switch being turned on when the output transistor is turned on and being turned off when the output transistor is turned off,

wherein the second reference voltage circuit comprises:

a constant current circuit connected between the power supply terminal and one end of the first switch;

a resistor element connected between the one end of the first switch and a ground terminal;

a voltage follower circuit configured to receive, as input, a voltage of the one end of the first switch;

a bleeder resistor comprising a first resistor, a second resistor, and a third resistor connected between an output of the voltage follower circuit and the ground terminal in the stated order; and

a second switch that includes one end connected to a node between the second resistor and the third resistor and another end connected to the ground terminal, the second switch being turned on when the output transistor is turned on and being turned off when the output transistor is turned off, and

wherein a voltage of a node between the first resistor and the second resistor reaches the second reference voltage.

3. A voltage regulator according to claim **2**, wherein the voltage difference sensing circuit comprises a transistor including a source connected to the power supply terminal, a gate connected to the output voltage, and a drain connected to the one end of the first switch.

4. A voltage regulator according to claim **3**, wherein the output current monitoring circuit comprises a transistor including a source connected to the power supply terminal, a gate connected to a gate of the output transistor, and a drain connected to the one end of the first switch.

5. A voltage regulator according to claim **2**, wherein the output current monitoring circuit comprises a transistor including a source connected to the power supply terminal, a gate connected to a gate of the output transistor, and a drain connected to the one end of the first switch.

6. A voltage regulator according to claim **2**, wherein the first switch and the second switch are controlled based on output of the comparator circuit.

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